Plant Atmosphere ammonia exchange: a modeling frame to include plant metabolism

MASSAD Raia Silvia

LOUBET B., TUZET A. and CELLIER P.

INRA - Environment and Arable Crops Research Unit

massad@grignon.inra.fr

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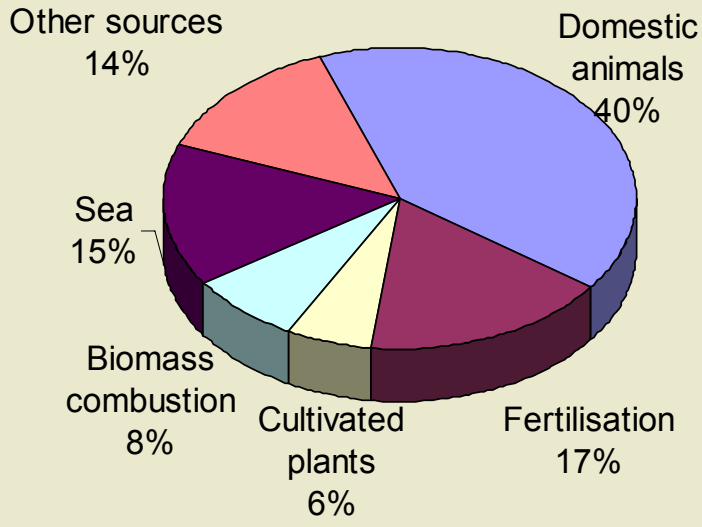
Why study vegetation-atmosphere ammonia exchange

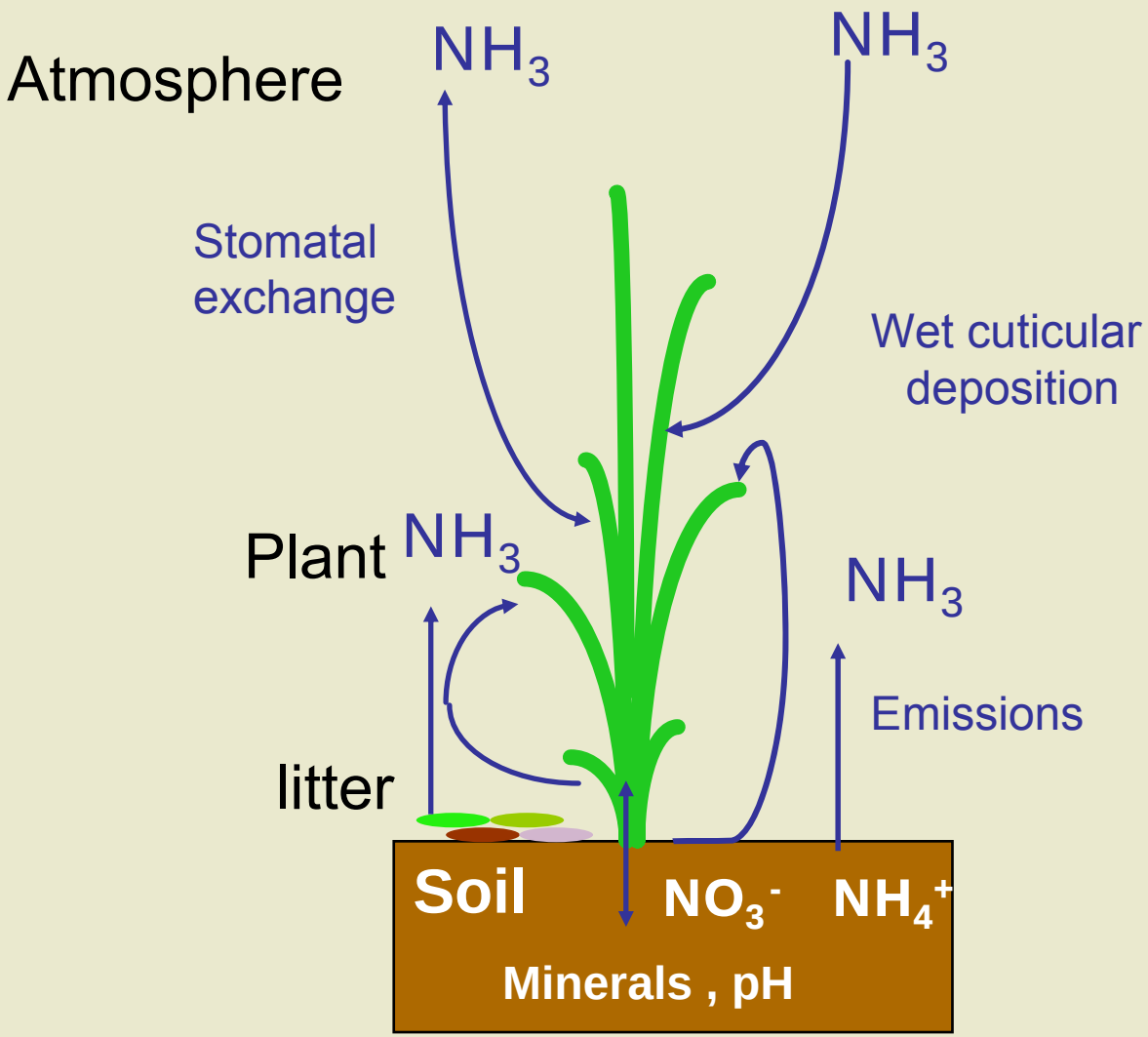
- Quantitatively emission and deposition fluxes are poorly defined
- Important gaps in the mechanistic understanding of the exchange process



Bouwman et al., 1997

- Livestock sources dominate point source emissions, evidence suggests that exchange with vegetation plays a major role in regulating both air concentrations and the extent of long-range transport (Langford and Fehsenfeld 1992; Sutton et al. 1994)

Vegetation-atmosphere NH_3 exchange

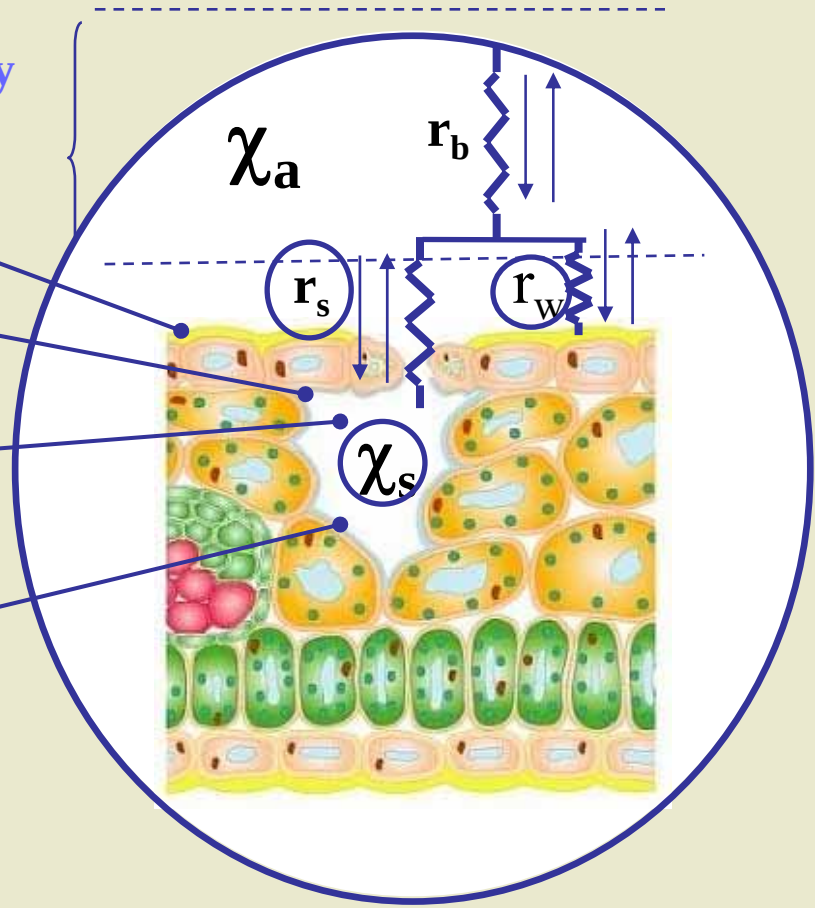


Leaf-atmosphere NH_3 exchange

$$F_{NH_3} = (\chi_s - \chi_a) \times g_t$$

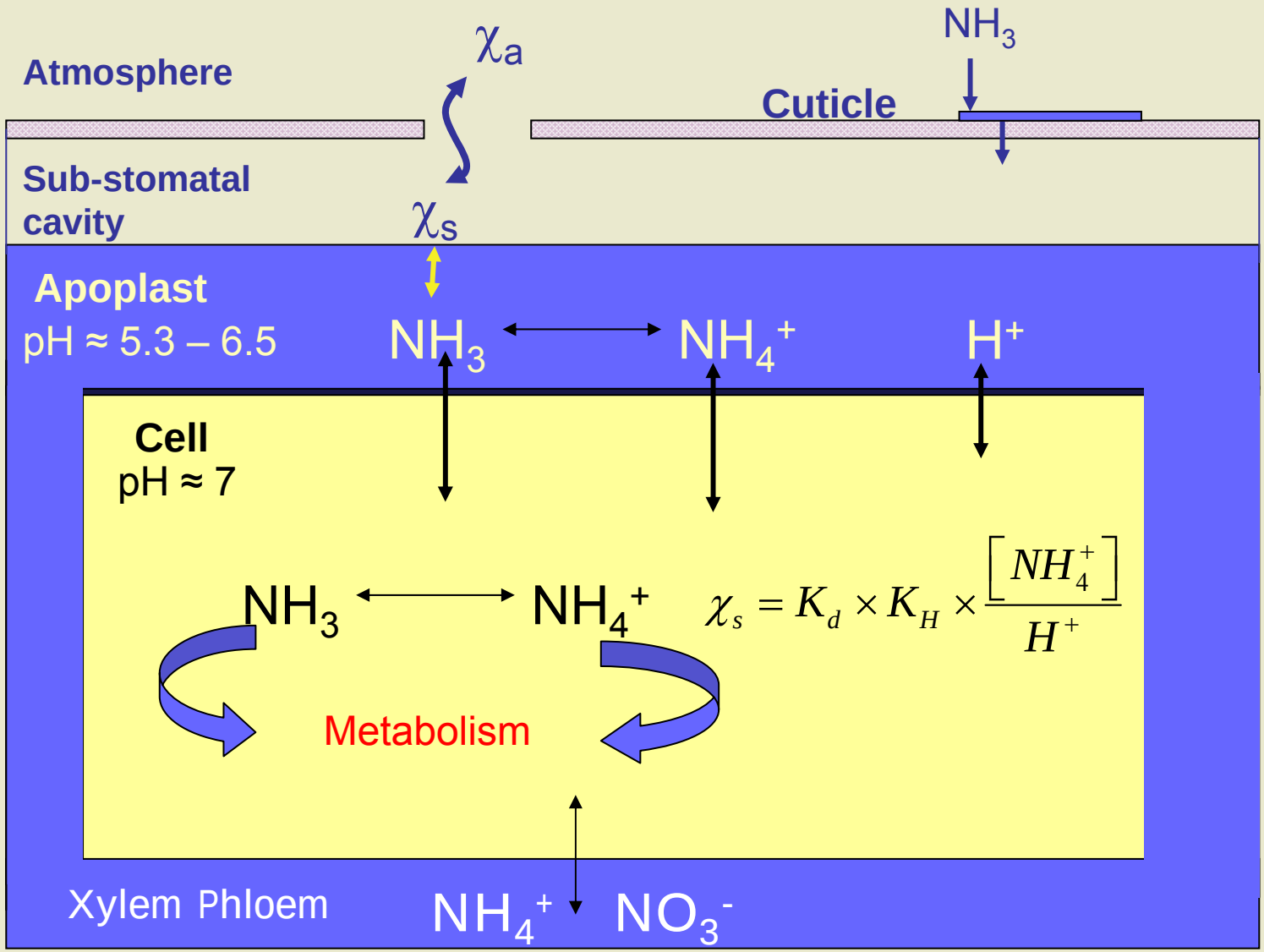
$$g_t = 1 / r_t$$

$$r_t = r_s + r_b$$



r_b : leaf boundary layer resistance
r_s : stomatal resistance
r_w : cuticular resistance
χ_s : Stomatal compensation point
χ_a: atmospheric ammonia concentration

Cell-atmosphere NH_3 exchange

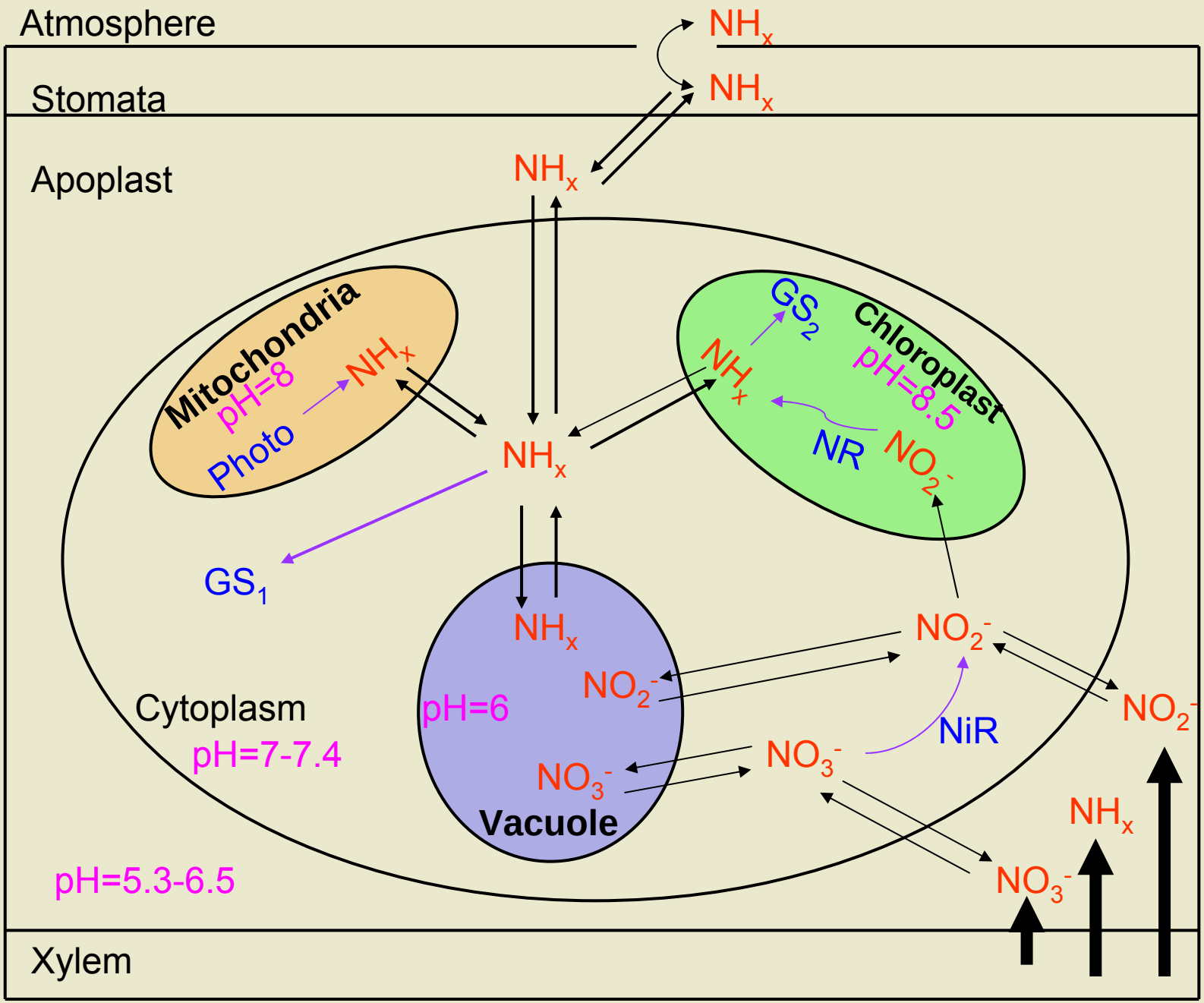


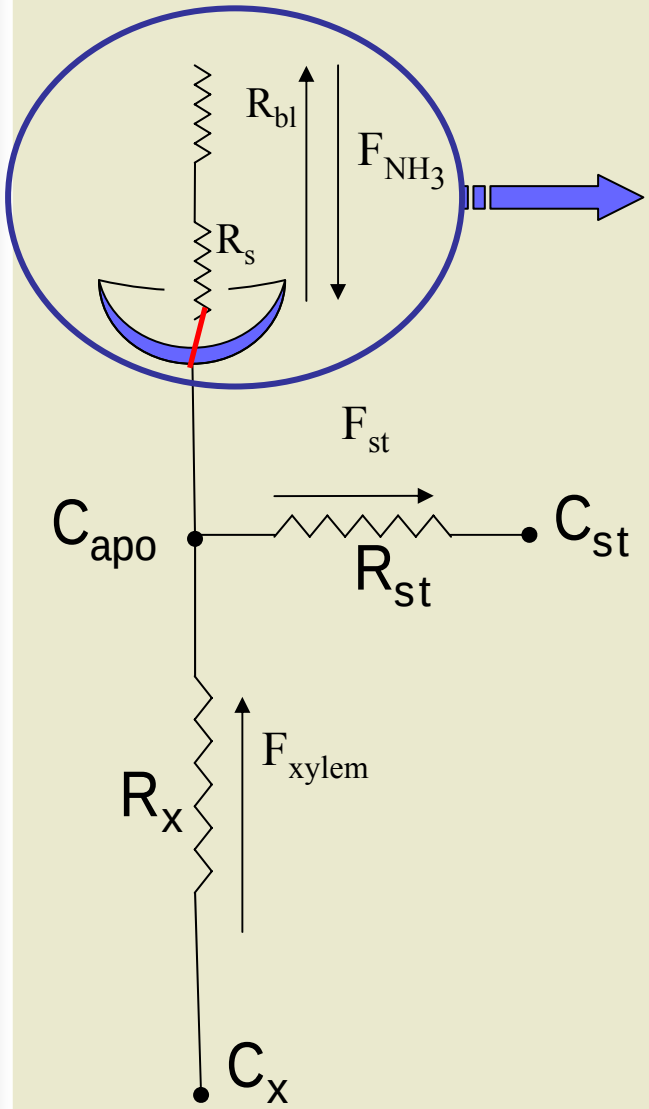
Cell metabolism & NH_3 exchange

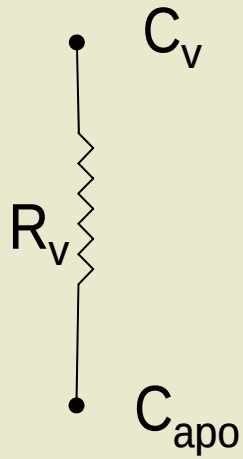
- $[NH_4^+]_{apoplast}$ depends on:
  - the balance of import via the xylem,
  - the absorption by cells,
  - and the export by the phloem.

- Assimilation occurs mainly via the GS/GOGAT cycle

- Production occurs via:
  - nitrate reduction,
  - photorespiration,
  - ureic catabolism,
  - lignin synthesis,
  - decomposition of glutamine and asparagine,
  - …

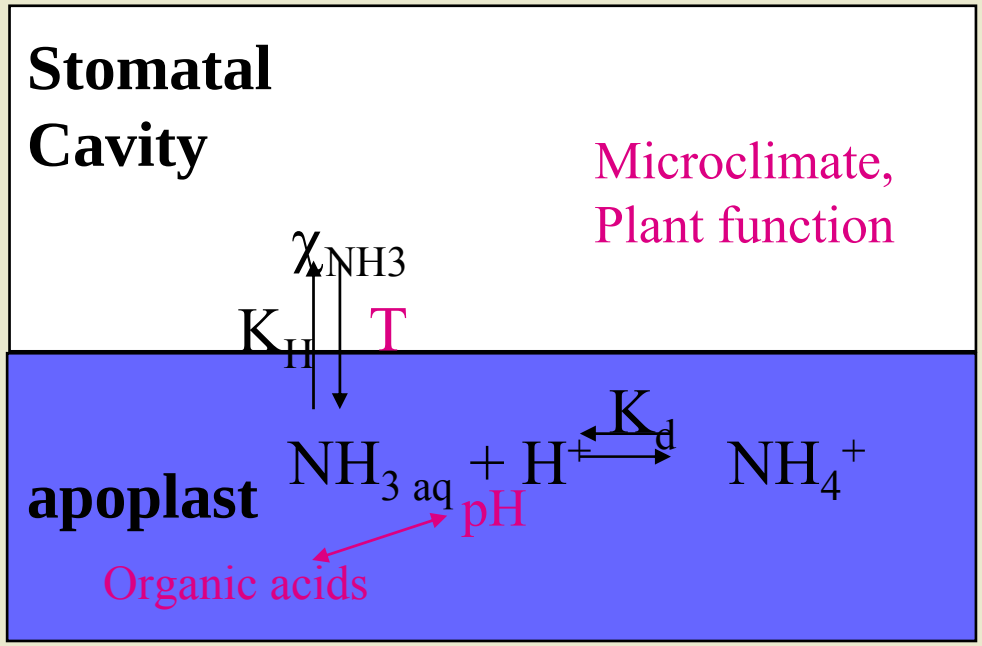

Atmosphere
Stomata
Apoplast
NHx
NHx
NHx
Mitochondria
pH=8
Photo
NHx
NHx
GS2
Chloroplast
pH=8.5
NR
NO2-
GS1
NHx
NO2-
NO2-
pH=6
NO2-
Cytoplasm
pH=7-7.4
NO3-
NiR
NO3-
Vacuole
NHx
pH=5.3-6.5
NO3-
Xylem

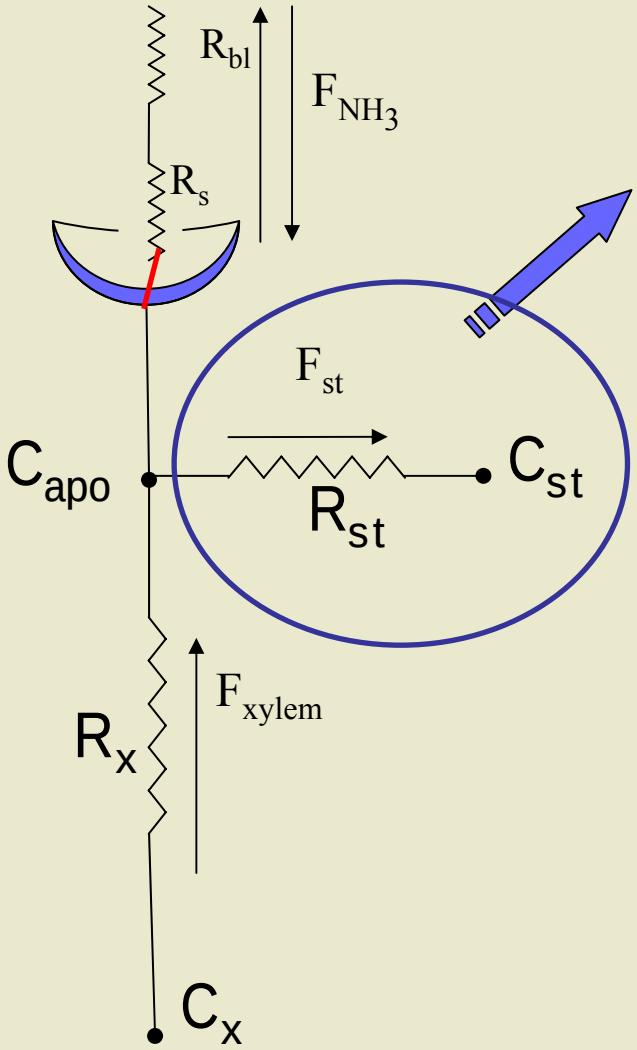


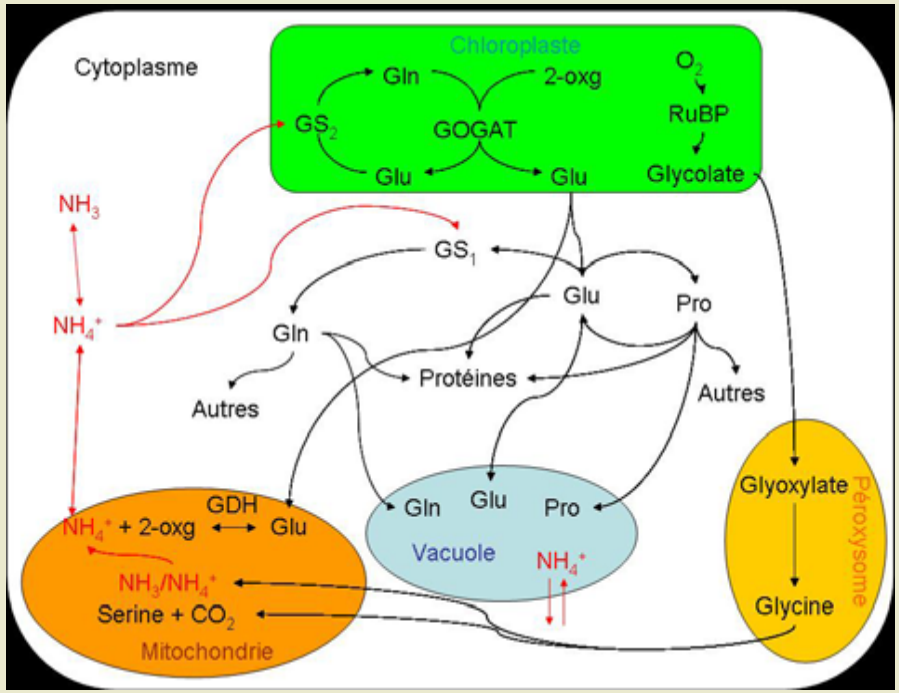


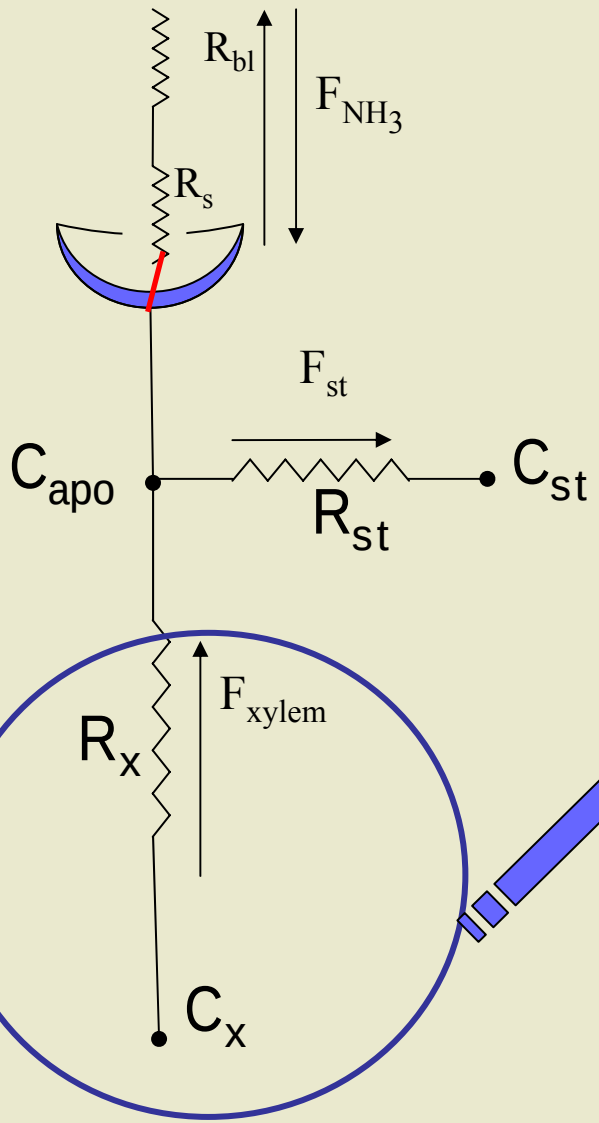
$$R_v = \frac{R_s \cdot [H^+] + R_{bl} \cdot [H^+]}{K_H \cdot K_d}$$

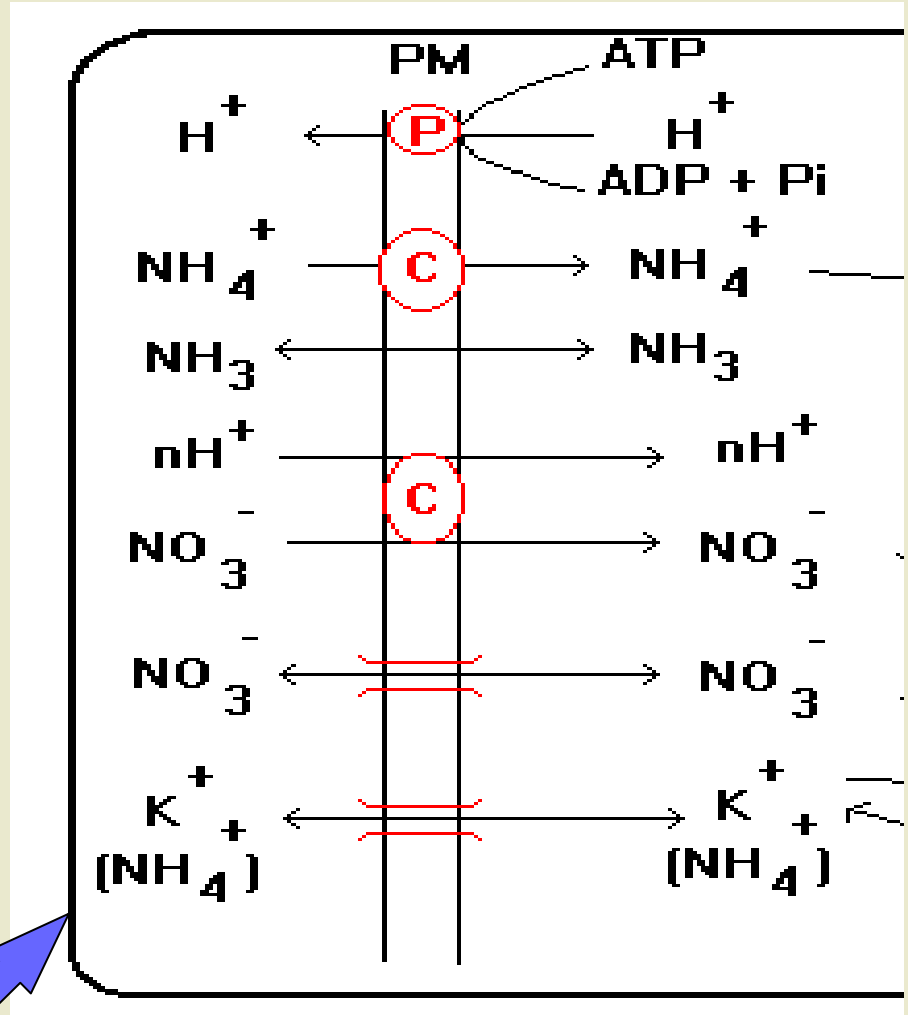
$$C_v = \frac{C_{atm} \cdot [H^+]}{K_H \cdot K_d}$$




R_{bl}
F_{NH_3}
R_s
F_{st}
C_{apo}
C_{st}
R_{st}
F_{xylem}
R_x
C_x


Cytoplasme
Chloroplaste
Gln
2-oxg
O_2
RuBP
GS_2
GOGAT
Glu
Glu
Glycolate
NH_3
GS_1
NH_4^+
Glu
Pro
Gln
Protéines
Autres
Autres
GDH
NH_4^+ + 2-oxg
Glu
Gln
Glu
Pro
Vacuole
NH_4^+
NH_3/NH_4^+
Serine + CO_2
Mitochondrie
Glyoxylate
Glycine
Péroxysome


R_{bl}
F_{NH_3}
R_s
F_{st}
C_{apo}
C_{st}
R_{st}
F_{xylem}
R_x
C_x


PM
ATP
H^+
P
H^+
ADP + Pi
NH_4^+
C
NH_4^+
NH_3
NH_3
nH^+
C
nH^+
NO_3^-
NO_3^-
NO_3^-
NO_3^-
K^+
(NH_4^+)
K^+
(NH_4^+)

Objectives

- Identify limiting processes in determining $[NH_4^+]_{apo}$
- Maintain a mechanistic approach
- Account for N-nutrition, environmental conditions, plant metabolism

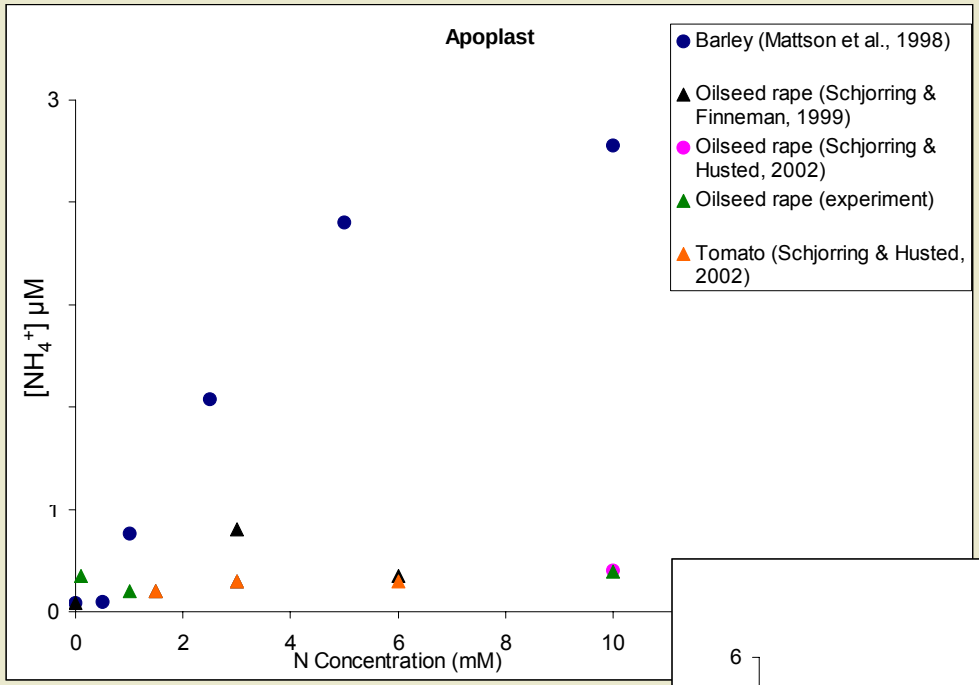
Procedure

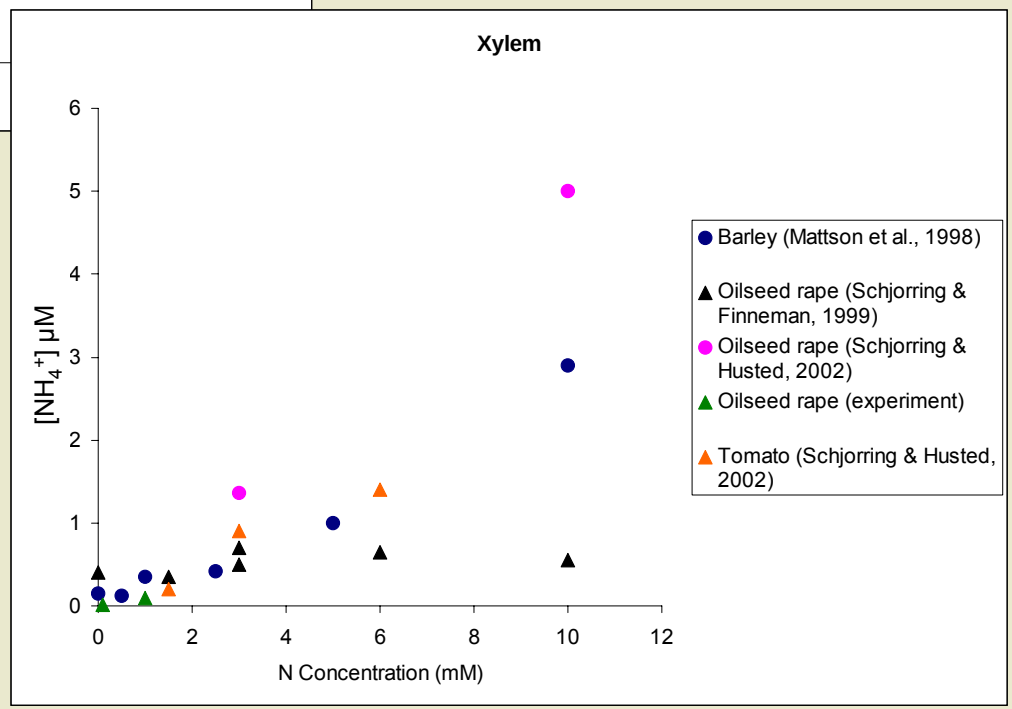
- Step 1: Collect data and do some experimentation
- Step 2: Conceptually validate each hypothesis
- Step 3: Estimate resistance values by combining data and equations
- Step 4: Use estimated resistances to calculate apoplastic concentrations and compare

Experiment

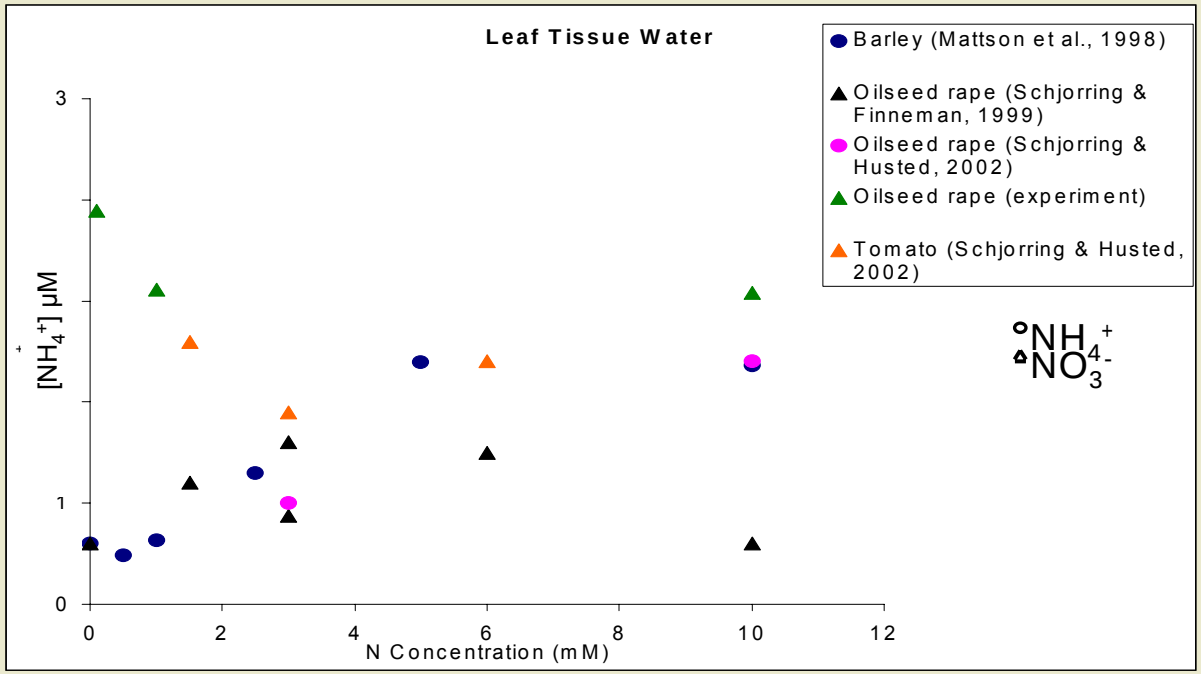
- Oil seed rape in phytotron with controlled conditions and grown hydroponically with different N treatments (0,1 mM NO_3^-, 1 mM NO_3^- ,10 mM NO_3^- and 5 mM NH_4^+)
- Extraction and measurement of ammonia concentrations and pH for:
  - apoplast by infiltration/centrifugation technique (Husted & Schjørring, 1995),
  - xylem
  - Leaf tissue water
- Photosynthesis measurements
- Total Carbon and Nitrogen contents

Data


Apoplast
Barley (Mattson et al., 1998)
Oilseed rape (Schjorring & Finneman, 1999)
Oilseed rape (Schjorring & Husted, 2002)
Oilseed rape (experiment)
Tomato (Schjorring & Husted, 2002)
[NH4+] µM
N Concentration (mM)
0
2
4
6
8
10
3
1
0


Xylem
Barley (Mattson et al., 1998)
Oilseed rape (Schjorring & Finneman, 1999)
Oilseed rape (Schjorring & Husted, 2002)
Oilseed rape (experiment)
Tomato (Schjorring & Husted, 2002)
[NH4+] µM
N Concentration (mM)
0
1
2
3
4
5
6
0
2
4
6
8
10
12

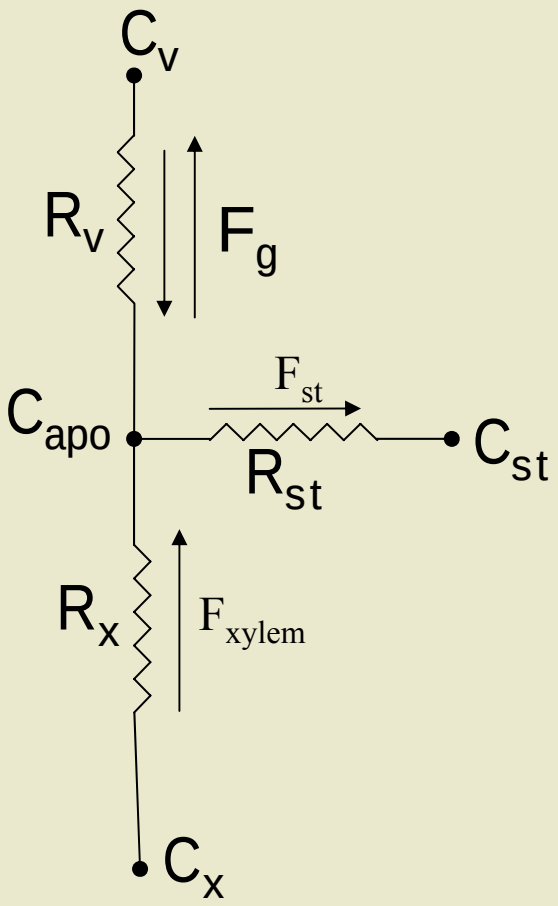
Data



$$F_x = C_x \times ET \qquad F_{st} = A \times {}^{N}\!/_{C} \qquad F_{NH_3} = (C_s - C_a) \text{ x } g_s$$

F_x (µmol m^{-2} s^{-1})	F_{st} (µmol m^{-2} s^{-1})	F_g (µmol m^{-2} s^{-1})
0.07	1.43	0.04
0.06	1.70	-0.02
0.14	2.60	0.01

Model equations



Hypothesis 1

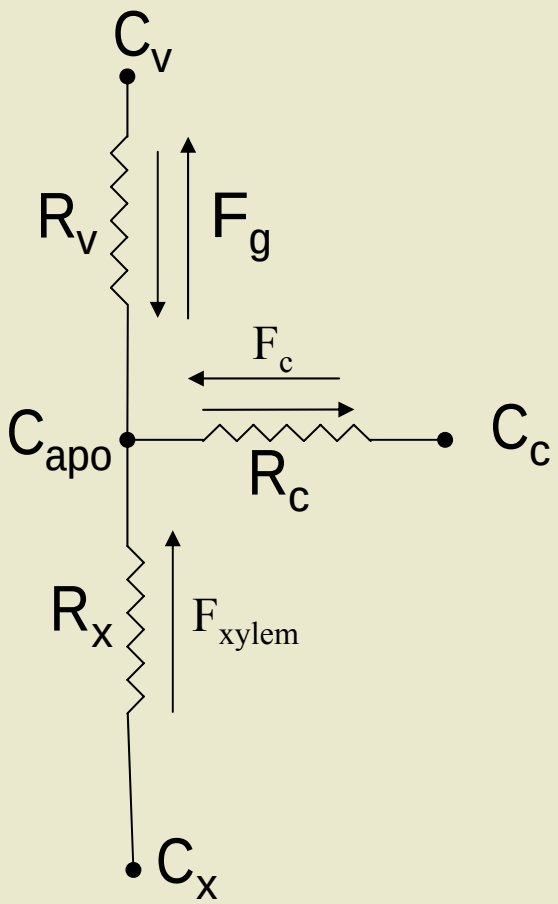
F_g negligible

$$C_{apo} = C_x \left(\frac{R_{st}}{R_x + R_{st}} \right)$$

F_g non negligible

$$C_{apo} = \left(\frac{C_x}{R_x} - F_g \right) \left(\frac{R_{st} \cdot R_x}{R_x + R_{st}} \right)$$

Model equations



Hypothesis 2

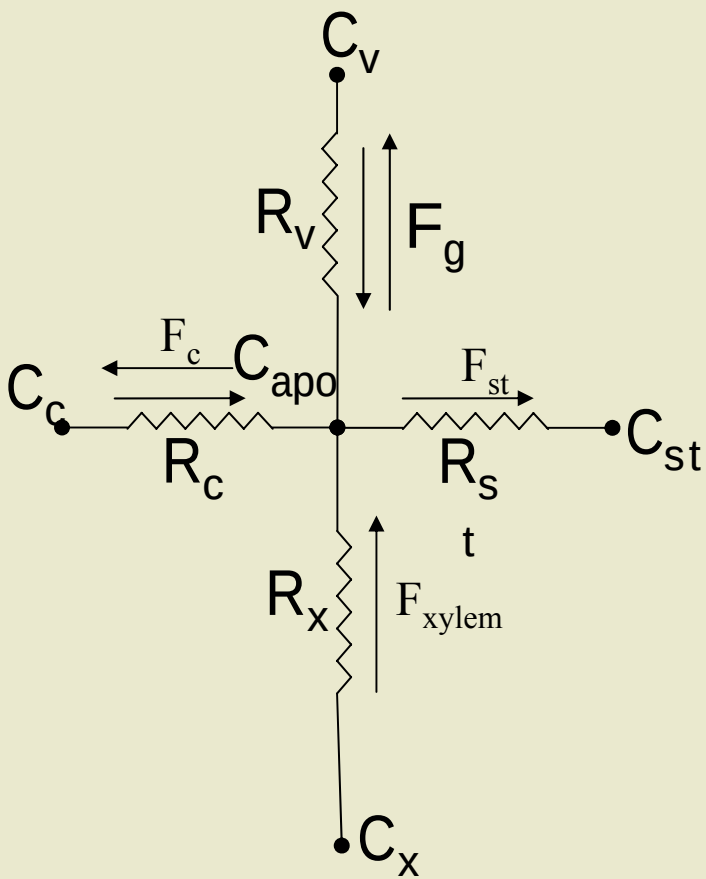
F_g negligible

$$C_{apo} = \left(\frac{C_x}{R_x} + \frac{C_c}{R_c} \right) \left(\frac{R_c \cdot R_x}{R_x + R_c} \right)$$

F_g non negligible

$$C_{apo} = \left(F_g + \frac{C_c}{R_c} + \frac{C_x}{R_x} \right) \left(\frac{R_c \cdot R_x}{R_x + R_c} \right)$$

Model equations



Hypothesis 3

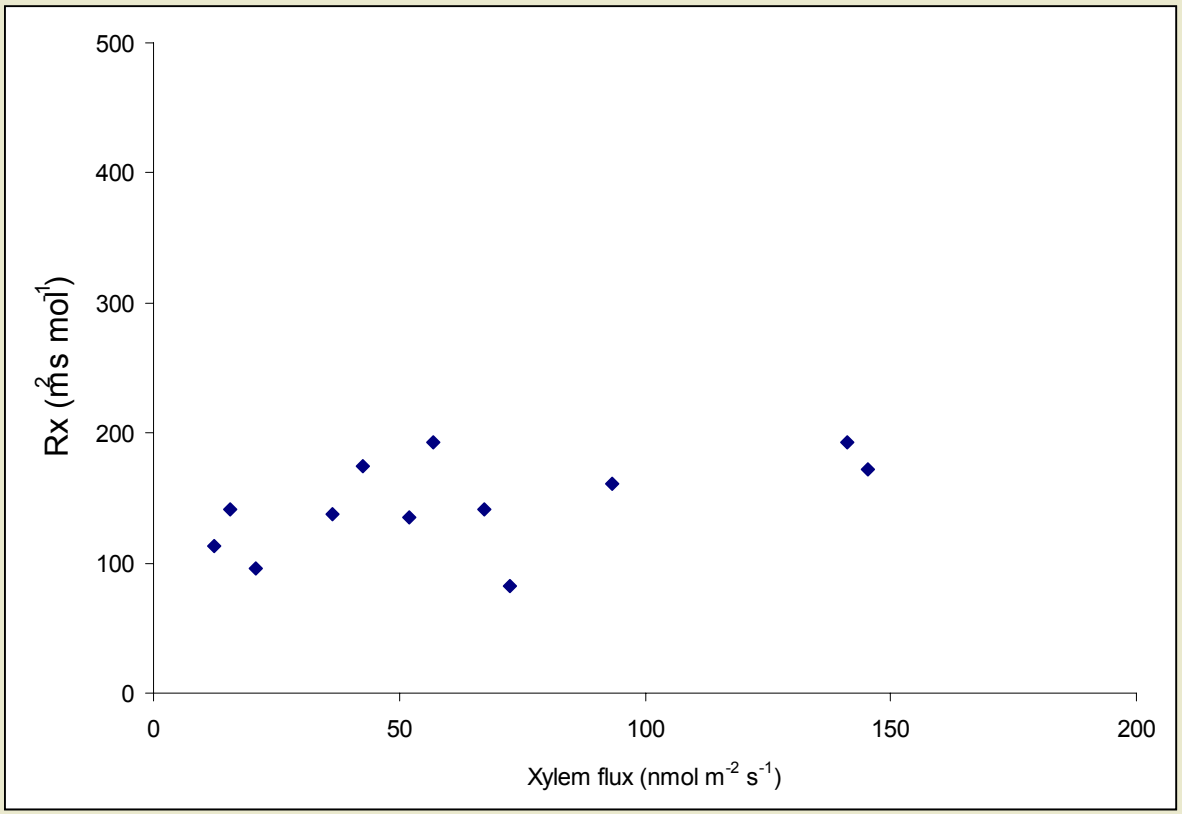
F_g negligible

$$C_{apo} = \frac{R_{st} \cdot R_c \cdot C_x + R_{st} \cdot R_x \cdot C_c}{R_x \cdot R_c + R_{st} \cdot R_c + R_{st} \cdot R_x}$$

F_g non negligible

$$C_{apo} = \frac{R_{st} \cdot R_c \cdot C_x + R_{st} \cdot R_x \cdot C_c - R_{st} \cdot R_x \cdot R_c \cdot F_g}{R_x \cdot R_c + R_{st} \cdot R_c + R_{st} \cdot R_x}$$

Estimation of Resistances



Hyp 1:

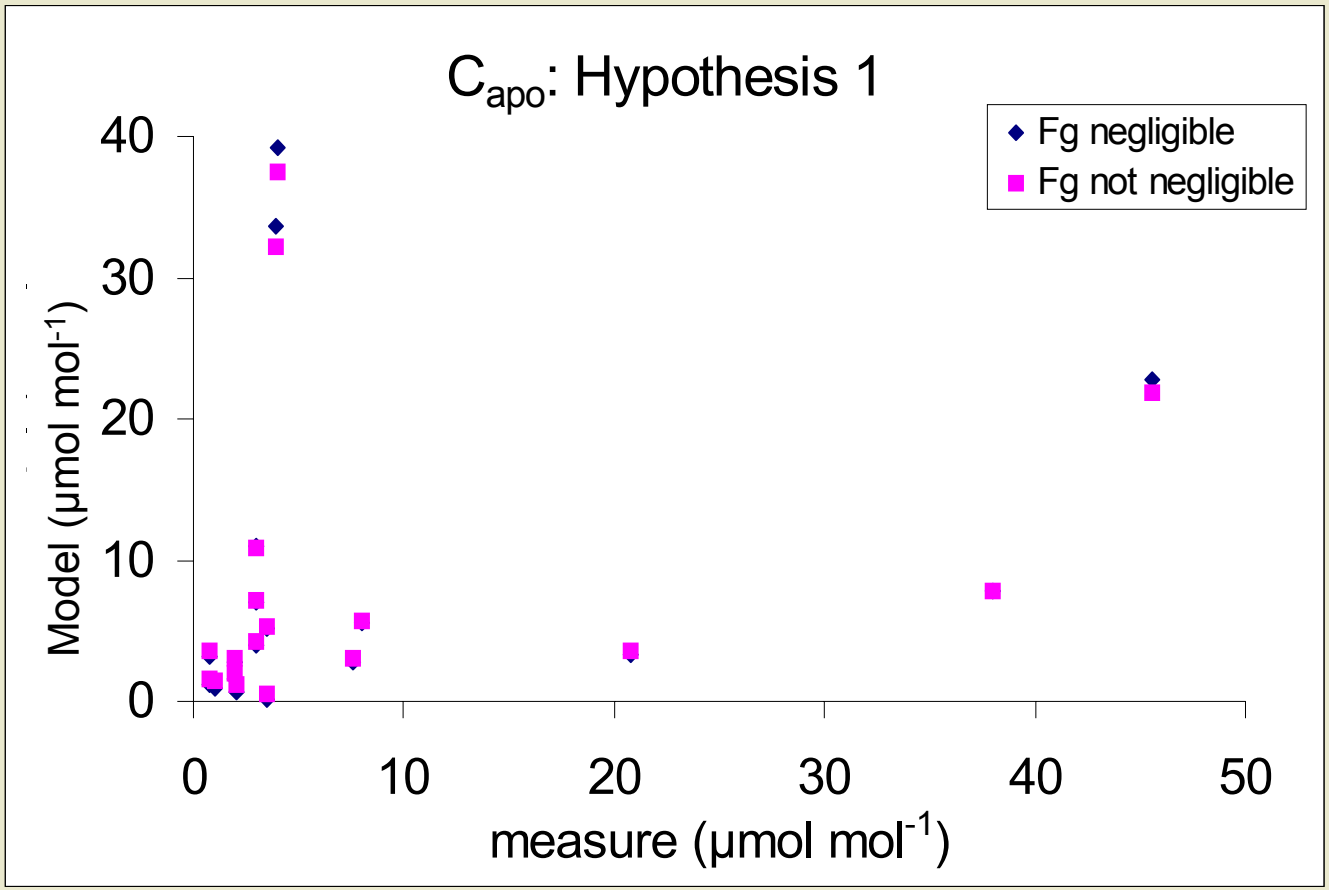
Rst =56 m^2 s mol^{-1}

Hyp 3:

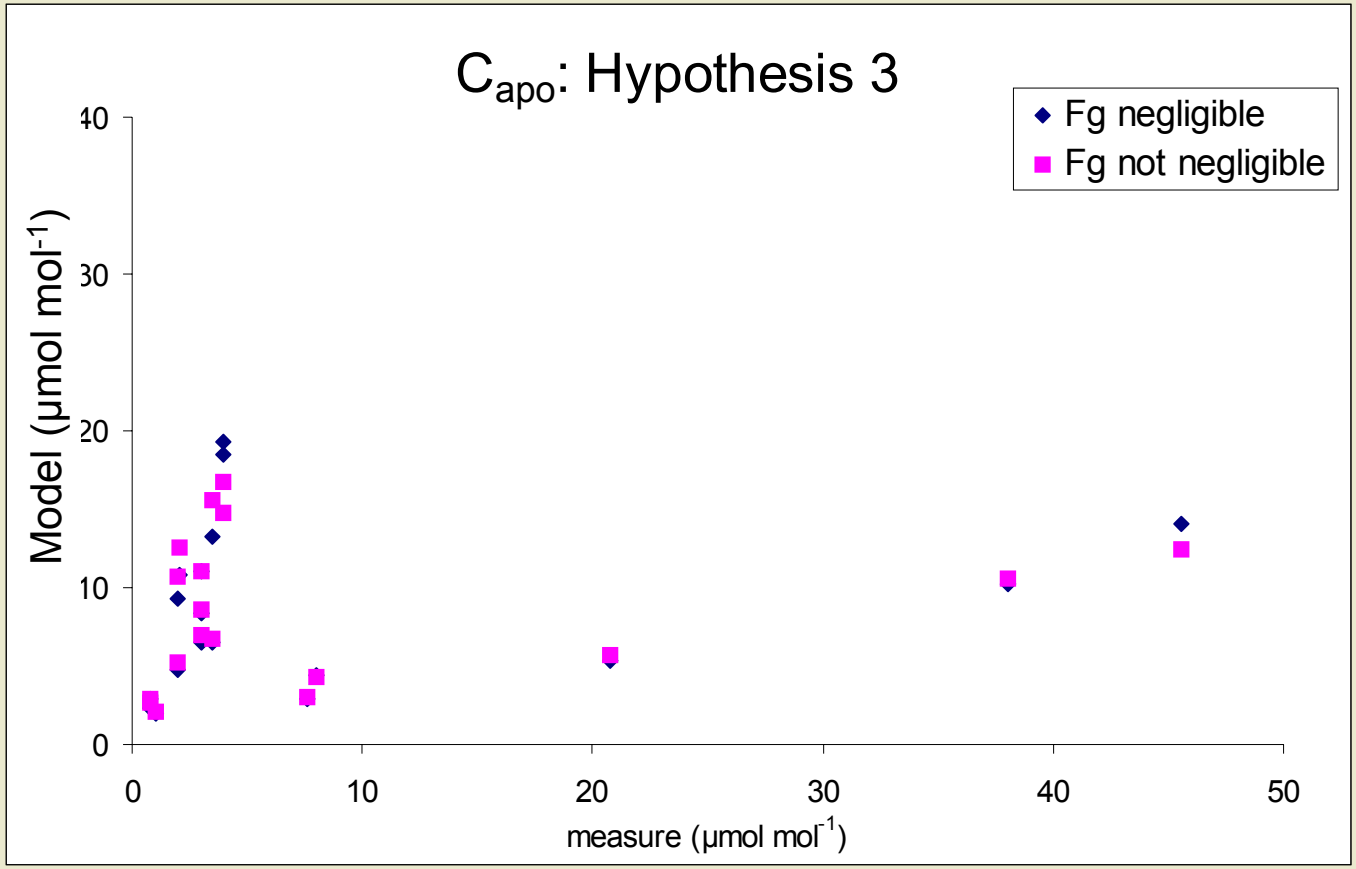
Rst =16 m^2 s mol^{-1}

Rc =26 m^2 s mol^{-1}

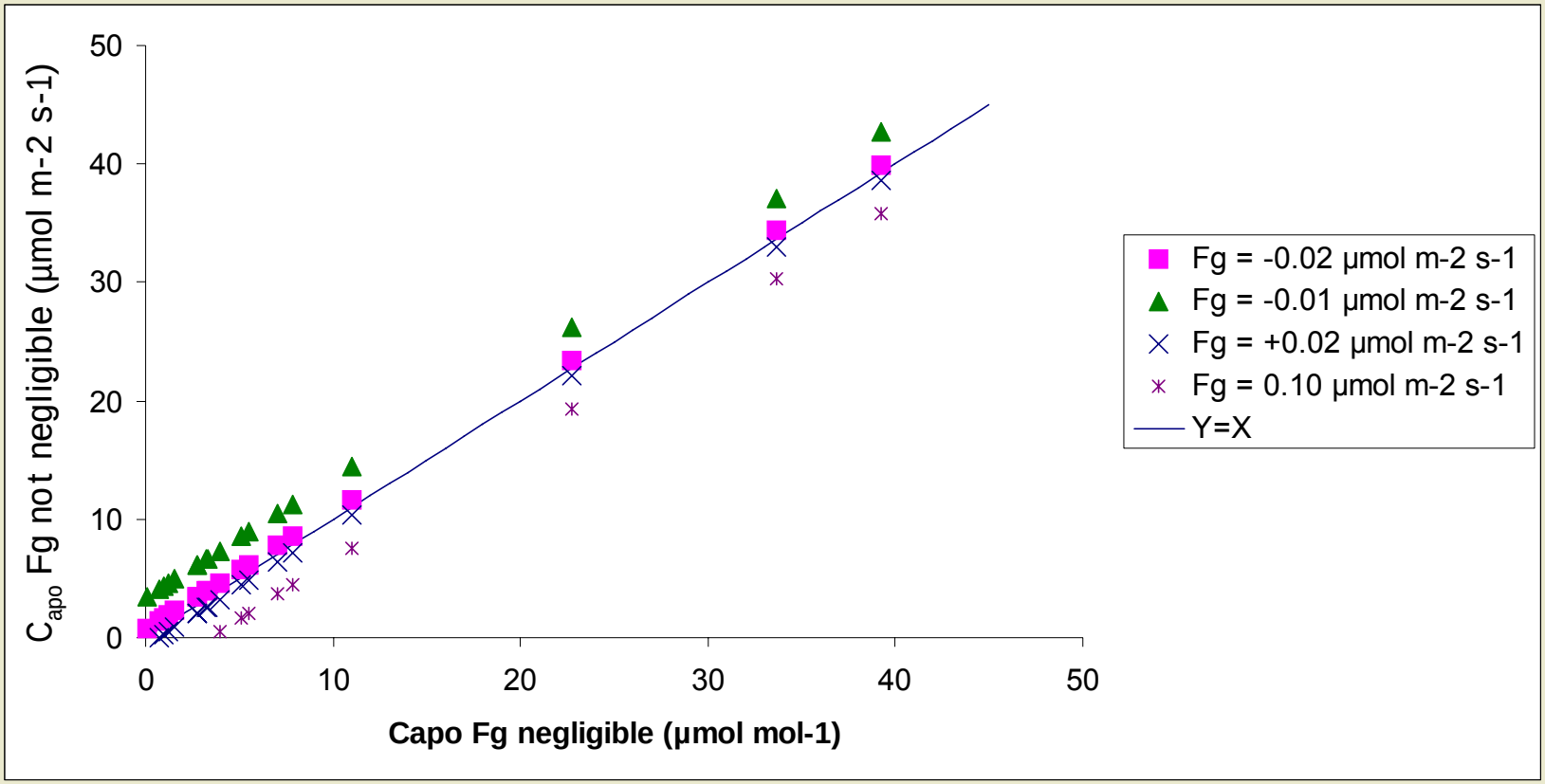
Hypothesis 1: Results



Hypothesis 3: Results



Effect of F_g on C_{apo}



Conclusions & Perspectives

- Possible explanation for difference between Flux measurement and extraction techniques
- Conceptually acceptable but doesn't account for some biological realities
- Have more adapted set of data
  - Flux measurements (Isotopic tracers)
  - Dynamic measurements
- Relate to Nitrate nutrition
- Relate resistances to biological functioning
- Integrate senescence through possibility of back flow from C_{st}
- Link to SVAT models